required, and no wall presses are used. Although the ultimate potential storage capacity of the building when complete may be extended to 600,000 volumes, at present only about 100,000 have to be provided for.

The arrangement of the books is according to a modification of the decimal system of Mr. Dewey, of the State Library of New York. It is claimed for this system that it brings together on the shelves all works of cognate character, be they general or specific.

Within the space available here it is not possible to fully illustrate this system, but a few lines may be devoted to explaining the general principles of the method. The whole Library must be regarded as being divided into nine libraries, numbered as follows: (1) Philosophy, (2) Religion, &c., (5) Natural Science, and up to (9) History. Each of these is again divisible, *if necessary*, into nine parts.

Thus the number 54 represents the 4th division (Chemistry) of the 5th class (Natural Science); 541 represents Theoretical Chemistry, and 5412 represents the 2nd division (Atomic Theory) of Theoretical Chemistry.

Every book as it is received in the Library will receive a number, which will at the same time indicate its place on the shelves, and be a summary of its contents.

When he receives the *title* from a reader, the attendant will, after a little practice, be able to go directly and without reference to the place marks, to the exact shelf or quarter of the stores by simply translating the title into its corresponding number.

One advantage of the system is that the special works contained in the Library on a given subject can always be seen together at a glance. It is needless to point out that the complex character of many books will furnish complex exceptions to the more simple nomenclature.

The Library, as an all-round, modern, working student's library in science and literature, is a very valuable one, though it is not at present so in the sense that it contains any particular literary treasures.

The administration of these several institutions, together with the Botanic Gardens at Glasnevin, and the Metropolitan School of Art, is carried on by the Science and Art Department, which is represented locally by the Director of the Science and Art Museum, under whom there are heads of the several departments and institutions. Two local bodies were created in 1877 to aid the Department in the supervision of these institutions, one the Board of Visitors of the Museum and Botanic Gardens, and the other the Council of Trustees of the National Library, the functions of the latter including the selection of books for the Library.

The total cost of the several institutions is provided in the annual estimates of the Science and Art Department which are voted by Parliament.

COMPARISON OF THE SPECTRA OF NEBULÆ AND STARS OF GROUPS I. AND II. WITH THOSE OF COMETS AND AURORÆ.[1]

II.

General Comparisons.

In the preceding article I showed that the spectra of nebulæ, auroræ, bright-line stars, and stars of Group II. are closely related to the spectra of comets. In the table which follows, all the spectra are brought together and compared. It is not sufficient to show that each group resembles comets in some respects, as each one might have some feature which was absent in the other. I therefore give the following table to show how far they resemble each other. In the last column the dark bands which are simply due to absence of radiation, and are not really absorption-bands, are omitted.

Nebulæ.	Aurora.	Comets.	Bright-line Stars.	Stars with Mixed Flutings.
4101	411	—	4101	—
—	426	[426]	—	—
—	431	431	—	449 (bright space)
434	435	—	434	—
447	—	—	—	—
—	—	—	—	461–451 bright
468–474	474–478	468–474	468–474	472–476 bright
479	482	483	—	—
486	486	486	486	—
4958	—	—	—	4958–486 bright
500	500	500	—	502–4959 dark
509	—	—	507	—
517	517	517	517	516–502 bright
—	519	519	—	—
520	522	521	—	522–516 dark
—	—	—	—	524–527 dark
527	—	[527]	527	—
—	531	—	—	—
—	535	—	—	—
—	539	—	540	—
546	545	546	—	544–551 dark
554	—	—	—	—
559	558	558	558	559–564 dark
—	—	561	—	—
—	—	564	564	—
—	—	568	568	—
—	—	[579]	579	—
—	—	—	—	585–594 dark
5872 (D_3)	—	—	5872	—
—	—	[589]	589	—
—	606	—	—	—
—	620	[615]	—	616–630 dark
—	630	—	635	—

It will be seen that there are three flutings which run through the five columns, namely, 468–474, 517, and 558—these are due to carbon and manganese, and are the familiar cometary bands; four more—hydrogen 486, magnesium 500, magnesium 521, and lead 546—occur in four out of the five columns. Out of the thirty-four lines or flutings given, there are nineteen which occur in less than three columns, but this number is greatly reduced when slight differences of temperature, masking effects, and the exceptional conditions of comets are taken into account.

It is now universally agreed that comets are swarms of meteorites, and the tables which I have given show that nebulæ, bright-line stars, stars with mixed flutings, and the aurora, have spectra closely resembling those of comets, the special features of which are the carbon bands, to which I have recently added the absorption bands of manganese and lead; all are therefore probably meteoritic phenomena.

The following is a list of the bodies which contain either one or both of the carbon flutings near 517 and 468–474, the latter being a group of flutings, which, as I have before shown (Roy. Soc. Proc., vol. 35, p. 167), sometimes has its point of maximum brightness shifted from 474 to 468. The fluting near 564 has been omitted from the table, as it is generally masked, either by continuous spectrum or by the superposition of the fluting of manganese near 558. The wave-lengths given are as measured by the various observers stated.

The spectrum of the aurora is added for the sake of completeness.

It will be seen from the table that the record of the presence of carbon is unbroken from a planetary nebula through stars with bright lines to those resembling α Herculis, *i.e.* entirely through Groups I. and II. of my classification.

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[1] Continued from p. 345.

Name.	Fluting 468-474.	Fluting 517.	Reference.
Planetary nebula	469·4 (Copeland)	— —	Copernicus, vol. 1, p. 2.
Nebula in Orion	470 (Taylor)	— —	Monthly Notices, vol. 49, p. 126.
Nebula, Gen. Cat., No. 4373.	— —	518 (Vogel)	Bothk. Beob., Leipzig, Heft 1, 1872, p. 57.
,, ,, ,, ,, 4234.	— —	518 (Vogel)	,, ,, ,, ,,
,, ,, ,, ,, 4390.	— —	518 (Vogel)	,, ,, ,, p. 58.
Nebula in Andromeda	468–474 (Fowler)	517 (Fowler)	Roy. Soc. Proc., vol. 45, p. 216.
,, ,,	— —	517 (Taylor)	Monthly Notices, vol. 49, 126.
γ Argûs	468 (Ellery)	— —	Observatory, vol. 2, p. 418.
,,	464·6 (Copeland)	— —	Copernicus, vol. 3, p. 205.
Arg.-Oeltzen, 17681	461–470 (Vogel)	— —	Astro-Phys. Obs. zu Potsdam, vol. 4, No. 14, p. 16.
,, ,,	473 (Pickering)	— —	Astr. Nachr., No. 2376.
Lalande, 13412	469 (Vogel)	— —	Astro-Phys. Obs. zu Potsdam, vol. 4, No. 14, p. 17.
1st Cygnus	470 (Wolf and Rayet)	— —	Comptes rendus, vol. 65, p. 292.
,,	465–470 (Vogel)	— —	Astro-Phys. Obs. zu Potsdam, vol. 4, No. 14, p. 17.
,,	468–474 (Fowler)	517 (Fowler)	New observations.
2nd Cygnus	470 (Wolf and Rayet)	— —	Comptes rendus, vol. 65 (1867), p. 292.
,,	464 (Vogel) middle of band	— —	Astro-Phys. Obs. zu Potsdam, vol. 4, No. 14, p. 17.
,,	468–474 (Fowler)	517 (Fowler)	New observations.
3rd Cygnus	470 (Wolf and Rayet)	— —	Comptes rendus, vol. 65 (1867), p. 292.
,,	461–468 (Vogel)	517 (Vogel)	Astro-Phys. Obs. zu Potsdam, vol. 4, No. 14, p. 17.
,,	468–474 (Fowler)	517 (Fowler)	New observations.
γ Cassiopeiæ	— —	517 (Sherman)	Astr. Nachr., No. 2691.
,,	468–474 (Fowler)	517 (Fowler)	New observations.
o Ceti	468–474 (Fowler)	517 (Lockyer and Fowler)	New observations.
α Herculis	468–474 (Fowler)	517 (Lockyer and Fowler)	New observations.
α Orionis	— —	517 (Lockyer and Fowler)	New observations.
Aurora	474–478 (Vogel)	— —	Bothk. Beob., Leipzig, Heft 1, 1872, p. 43.
,,	— —	517 (Backhouse)	Nature, vol. 7, p. 463.

We have now to inquire into the previous work on this subject.

Carbon in Stellar Spectra.

Secchi, in 1869, was the first to call attention to the possible existence of indications of carbon in stellar spectra in connection with stars of his types III. and IV.[1] He even compared the spectrum of 152 Schjellerup with the carbon spectrum obtained from benzene. His micrometric measures of the distances of the principal bands in the two spectra from the sodium line D gave great weight to his statement.[2]

But although Secchi observed the coincidence of the edges of two dark bands in his types III. and IV., and remarked that the light-curve in one case faded towards the red, and in the other towards the violet end of the spectrum, he did not recognize that we were dealing with radiation in one case and absorption in the other.

Indeed, Secchi regarded type IV. as presenting chiefly radiation phenomena, for later,[3] when writing with respect to stars of this type he states:—

"Quelques-unes des raies noires et les plus importantes, coincident à très-peu-près avec celles du troisième type; cependant le spectre, dans son ensemble, *se présente comme un spectre direct appartenant à un corps gazeux*, plutôt que comme un spectre d'absorption. Si on le considère comme un spectre d'absorption, on trouve qu'il présente le caractère des composés du charbon, tels qu'on les obtient en produisant une série d'étincelles électriques dans un mélange de vapeur de benzine et d'air atmosphérique et dans l'arc voltaique entres les charbons."

From the foregoing, it is evident that Secchi had observed the coincidence of the flutings of carbon with the dark flutings in stars in his fourth type, but missed the significance of it altogether.

Dr. Huggins, however, in a footnote to the first edition of Schellen's "Spectrum Analysis," edited by him, gave an observation of his of the spectrum of 152 Schj., and a diagram of the spectrum of this star, which combated Secchi's work. In his words:—

"He compared the spectrum of the star, using a narrow slit, with the bright lines of sodium and carbon. The line marked D he found to be coincident with that of sodium. The less refrangible boundary of the first of the three principal bright bands in the spectrum of carbon is nearly coincident with the beginning of the first group of dark lines; the second of the carbon bands is less refrangible than the second group in the star; the third band of the carbon spectrum falls on the bright space between the second and third group of dark lines in the spectrum of the star. The absorption bands are therefore not due to carbon."

Vogel, in 1884, showed that Dr. Huggins's observations were inaccurate; that the bands really did coincide with the carbon bands; and that Secchi's statement was perfectly correct with regard to this star (152 Schjellerup).[1]

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[1] *Atti dell' Acad. de' Nuovi Lincei*, xxv., 1872.

[2] These and other comparisons led Secchi to note:—"La conclusione è che nelle stelle di 4^o tipo vi é certo il carbonio in una combinazione di debole tensione coll' idrogeno, é che questa combinazione esiste nello stesso stato, o in altro prossimo anche in quello di 3^o tipo."

[3] "Le Soleil," vol. ii. p. 458.

[1] "Neben dem Spectrum des Natriums erschienen noch ganz schwach zwei Banden des Alkohol-spectrums, die vollkommen mit den dunklen Banden des Sternspectrums zu coincidiren schienen. Der Anfang der ersten Bande des Alkoholspectrums wurde zu $+14' \, 37''$ gemessen. Auf den Anfang der zweiten Bande wurde wiederholt der Faden gestellt, und coincidirte jedesmal der Faden so vollkommen als möglich mit der Bande im Sternspectrum. Auch directe Vergleichungen zwischen Alkoholspectrum und Sternspectrum konnten gemacht werden, da das Sternspectrum hell genug war und sich ganz gut von den das ganze Gesichtsfeld durchsetzenden mattleuchtenden Banden des Alkoholspectrums abhob." Following some measures made on June 1, it is noted:—"Bei den Vergleichungen mit dem Natrium- und Alkoholspectrum wurde wiederholt die Ueberzeugung gewonnen, dass eine Coincidenz mit den Natrium-Linien, sowie mit den beiden stärksten Banden des Kohlenwasserstoffspectrums im Spectrum der Flammen und des Sternes stattfand. Ich setzte an diesem Abend, da der Himmel besonders gunstig war, noch das stark zerstreuende Rutherfurd'sche Prisma ein und konnte damit wenigstens die beiden stärksten Banden im Sternspectrum messen und wiederum durch directe Vergleichung die absolute Coincidenz der hellsten Bande des Kohlenwasserstoffspectrums mit einer Bande des Sternspectrums beobachten." In summing up the observations of the spectrum of this star Prof. Vogel remarked, "Vergleicht man diese Beobachtungen mit den Seite 14 angeführten des Kohlenwasserstoffes, so ergiebt sich zweifellos das Vorhandensein von Kohlenwasserstoff in der Atmosphäre des Sternes."—"Astrophysikalischen Observatoriums zu Potsdam," No. 14, p. 23, 1884.

Similar comparisons of the carbon spectrum with the spectra of other stars of the same type were made, and the coincidences led Vogel to the following final conclusion :—

"Die charakteristischen Banden dieser Sternspectra scheinen durch die Absorption von Kohlenwasserstoffen, die in der Atmosphäre der betreffenden Sterne vorhanden sind, hervorgebracht zu werden."

Quite recently, Mr. Maunder, in commenting upon the Rev. T. E. Espin's admirable revision of Birmingham's "Red Star Catalogue," wrote :[1] "In the note on No. 364 [152 Schjellerup], it should surely have been made clear that the difference between Secchi's and Huggins's account of its spectrum was due to the one having compared it with the spectrum of a hydrocarbon, and the other with that of carbonic oxide, and that the perfect accuracy of Huggins's description has been abundantly confirmed, though, for the reason just given, he missed the recognition of the absorption bands of the stellar spectrum as those of carbon."

Mr. Maunder here refers—I presume with authority—to a statement made by Dr. Huggins which I have not been able to trace. In the note already quoted, Dr. Huggins refers to the spectrum of carbon without giving any idea of the actual compound used for making the comparison, and I have not been able to find any subsequent statement which justifies Mr. Maunder's remarks. Further, it is not sufficient to simply state the compound used, as the spectrum obtained depends upon the conditions of experiment. It does not follow, therefore, that, even if carbonic oxide were employed, the spectrum obtained was not the so-called "hydrocarbon" spectrum. I fancy that now most workers are agreed that the band at 517 is a true carbon band, and obtainable, therefore, from any carbon compound.

Dunér, in 1884, discussed the evidence as to carbon absorption in stars of type IV.[2] The mean wave-lengths. given by him for the bands in this group are compared with those found by Vogel in the following table :—

Number of Dunér's band.	Wave-length. μμ	Vogel's measures.	μμ
		Spectrum begins	660
		Band	656
2	621 ...	Band	622
3	604·8 ...	Band	606·5
4	589·8 ...	Line in a band	589·3
		End of the band	584·8
5	576·0 ...	Line	575·7
6 (beginning)..	563·3 ...	Line, beginning of a band	563·1
7	551 ...	Line	552
6 (end)	545 ...	Line	544
8	528·3 ...	Group of lines	528
9 (beginning)..	516·3 ...	Line, beginning of a band	515·9
		Line	513·2
9 (end)	496		
10 (beginning)..	472·7 ...	Beginning of a band ...	472·9
10 (end)	463		
End of spectrum	437 ...	Band	437
		Spectrum ends	430

Dunér compared Vogel's measures and his own with the following wave-lengths of the hydrocarbon bands said to be given by Hasselberg :—[3]

		μμ.
Beginning of band	1	618·7
End ,, ,,		594
Beginning of band	2	563·4
End ,, ,,		543
Beginning of band	3	516·4
End ,, ,,		507
Beginning of band	4	473·7
End ,, ,,		467
Maximum ...	5	436·7
Beginning of band	6	431·9
End ,, ,,		423

These values differ slightly from those measured by Hasselberg in 1880, and given in the work referred to by Dunér.

From a comparison of the two sets of wave-lengths, those found in the spectrum of a body of type IV. and those given by Hasselberg, Dunér concluded that :—

"Les longueurs d'onde des bandes 6, 9 et 10 dans les spectres III.*b* sont donc à considérer comme identiques à celles des bandes 2, 3, et 4 dans le spectre de l'hydrogène carboné. Mais aussi la longueur d'onde 437 de la bande au violet, où pour mon réfracteur était la fin du spectre, et la longueur d'onde 430 de la fin du spectre visible selon M. Vogel, sont d'accord avec les deux bandes violettes de l'hydrogène carboné. On peut donc régarder comme extrèmement probable que :

"*Les bandes principales dans les spectres III.b sont dues à l'absorption exercée par un composé du carbon qui se trouve dans les atmosphères de ces étoiles.*"[1]

It will be seen from the passage which I have given in a note that most of the discussion had turned on the coincidence between bright carbon bands seen in the laboratory and dark absorption bands seen in stellar spectra (type IV.). It is not a little curious to see Dunér, in the passage I have underlined, holding to a possible similarity between stellar and cometary structure based upon carbon radiating in one case and absorbing in the other.

The next important advance was made by Dr. Copeland, who, in January 1886, in a communication to the Royal Astronomical Society on the spectrum of a new star in Orion, wrote as follows :—[2]

"The spectrum is unmistakably of the third type, of which α Orionis is the brightest member. But in this star the *bright bands* are so strikingly developed that they form the most salient parts of the spectrum. Adopting this view an examination of the preceding numbers and the descriptions of the bands, &c., to which they refer, reveals the startling fact that this spectrum is not so much a continuous one, interrupted by dark lines and dusky bands, as a *not very luminous spectrum upon which a series of bright bands are superposed.* One of the bright bands, that beginning with the 'very bright line,' W.L. 516·2 m.m.m. is most readily identifiable as the great hydro-carbon band seen in the spectrum of every comet that has been examined under favourable circumstances. This identification is strongly supported by the second bright line, 513·7, which is also found both in hydro-carbon and cometary spectra. It is, however, on bringing the spectra of the star and of the blue flame of a spirit-lamp at the same time into the field of the spectroscope that their exact agreement becomes most evident. For not only do they agree perfectly in wave-length and in beginning with two plainly distinguishable bright lines, but also in the delicate gradations of light by which they similarly fade away towards the violet, thus forcing the extreme probability of a common origin upon the observer.

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[1] *Observatory*, No. 164, July 1890.

[2] "Sur les Étoiles à Spectres de la Troisième Classe," Stockholm, 1884.

[3] "Ueber die Spectra der Cometen," p. 21.

[1] Dunér, in his conclusions as to the spectra of stars of Class III., wrote :—

"Si l'on passe ensuite à considérer le développement ultérieur de l'étoile, il est évident qu'à mesure qu'elle se refroidit davantage, elle parvient enfin à une température ou le carbone qui doit se trouver en abondance, soit dans son atmosphère soit sous une forme quelconque dans son photosphère, peut se combiner avec l'élément l'hydrogène ou un autre, qui ensemble avec le carbone donne origine au 'Spectre de Swan.' A partir de cela, le spectre se montre coupé par une large et faible bande à la longueur d'onde 516 mm. et par une autre encore plus pâle à 473 mm., et les parties du spectre au-delà de celle-ci sont très faibles. Mais peu à peu ces deux bandes gagnent en intensité, et en même temps la bande à 563 mm. se fait valoir, d'abord à peine visible, puis de plus en plus forte. A cette époque se développe la bande étroite à 576 mm., et finalement les trois bandes principales sont presque égales entre elles en intensité, et on reconnait, dans le spectre, tous les détails caractéristiques. Ce serait s'engager dans une discussion inutile si l'on voulait seulement exprimer une supposition sur le moment ou les bandes secondaires dans le rouge et dans l'orange font leur apparition, aucun fait n'étant connu qui pût être cité à l'appui.

"Ce qui est sans doute très remarquable c'est que dans les spectres III.*b* on n'aperçoit trace de la bande carbonique à la longueur d'onde 618·7 mm. laquelle est si brillante dans les tubes de Plücker contenant de l'hydrogène carboné. Ceci est au reste en parfaite analogie avec ce qu'on voit dans les spectres des comètes qui doivent leur apparence au même composé carbonique qui les spectres stellaires III.*b*, et il y a des analogies aussi pour les autres bandes. Ainsi la bande à 563 mm. est souvent bien faible même dans de brillantes comètes, et la bande dans le vert est toujours la plus forte, aussi bien dans les comètes que dans les étoiles. La bande dans le bleu est quelquefois assez faible dans les spectres cométaires, tandis que dans les étoiles elle est seulement un peu plus faible que la bande dans le vert ; mais il faut se souvenir qu'elle est située dans une partie déjà très faible dans les spectres des étoiles. Il est donc fort possible qu'un affaiblissement médiocre suffise pour rendre entièrement imperceptible la lumière restante. *Il n'y a donc peut-être pas à voir dans cela une diversité entre les comètes et ces étoiles.* Quant aux bandes violettes, elles sont très faibles dans les tubes de Plücker mais fortes dans le spectre de la flamme de l'alcool. On en a vu une trace dans les spectres des comètes les plus brillantes. Dans les étoiles III.*b* très brillantes et pas trop rouges, on a aussi une zone violette laquelle se termine, comme les mesures montrent, à la longueur d'onde 430 mm. donc à la position de la seconde de ces bandes, et à la position de la première il y a, dans les spectres de ces étoiles, une bande."

[2] *Monthly Notices R.A.S.*, vol. xlvi., p. 112

"But the presence of luminous lines does not rest on this single band, for the second cometary and hydro-carbon band which has its bright edge at W.L. 472·9 (Hasselberg, 'Ueber die Spectra der Cometen') is also found in the new star's spectrum at W.L. 472·2.

"Of the three other luminous bands agreeing with the coal-gas spectrum, which were all measured at Dun Echt in that of comet 1881 III.,[1] two lie beyond the limit to which I have yet traced the spectrum of this star, and the third, falling between W.L. 563 and 534, in a bright and otherwise difficult part of the spectrum, has not made its possible presence evident.

"This leaves the origin of the bright bands beginning at 542·8 and 494·4 an open question; but excepting their general appearance, there is no reason why they should be due to the same substance as the great band at 516·2. On the other hand, the presence of the bright hydro-carbon bands in a spectrum of type III. removes any difficulty there may be in accepting Secchi's conclusion that they appear in a reversed (dark) form in spectra of type IV."

Dr. Copeland also made determinations of the position of the bright bands in Nova Andromedæ,[2] and noted—

"It seems probable that the three 'bright' bands, of wave-lengths 546·8, 514·0, and 489·2, are identical with the three brightest bands afterwards measured with the same apparatus in Mr. Gore's Nova Orionis, of which the brightest parts were at wave-lengths 542·8, 516·2, and 494·4. The trace of a condensation of light at W.L. 471·6, seen on September 20, agrees well with the bright line in Nova Orionis at W.L. 472·2. . . . In conclusion, it seems worthy of remark that the spectrum described above is the same as that given by any ordinary hydro-carbon flame, burning so feebly that the spectrum of the blue base of the flame is just beginning to show through the continuous spectrum afforded by the white part of the flame."

Vogel made some observations of Nova Orionis,[3] and found that the wave-lengths of the absorption bands were the same as those of α Orionis and other stars of that group, the only difference being that the bright spaces were more strongly marked. Dunér also noted[4] very bright parts in the green and blue, which he identified as the bright zones 516·8–503·2 and 495·8–484·3. With respect to these bright parts, he thought they may be partly due to the contrast with the very dark and broad bands.

M. Ch. Trépied observed that the spectrum of Nova Orionis was like α Orionis and β Pegasi. He also remarked:—[5]

"Le 23 décembre, j'ai, pour la première fois, soupçonné l'existence de lignes brillantes dans le vert; mais cette observation est un peu incertaine. On sait combien il est difficile de décider si les apparences de lignes ou de bandes brillantes, dans un spectre faible, sont vraiment celles qui caractérisent l'état d'incandescence d'une matière gazeuse, ou s'il faut les attribuer à un effet de contraste causé par le voisinage des bandes obscures."

M. Thollon observed the same Nova, and recorded—[1]

"Ce qui nous frappa tout d'abord fut l'éclat remarquable du rouge et surtout du vert, tandis que le jaune était relativement sombre. Cette particularité nous suggéra d'abord l'idée que nous nous trouvions en présence d'un spectre de bands brillantes, analogue à celui des comètes, mais bien plus compliqué. Les observations comparatives faites sur α d'Orion nous confirmèrent dans cette idée. Cette étoile, en effet, montre avec une parfaite évidence un spectre continu conservant partout l'éclat qui lui est propre, et coupé par des bandes et raies obscures."

With the exception of Dr. Copeland, however, no observer confronted the spectrum of the Nova with that of carbon, or the identification of the bright spaces with the carbon flutings would have been evident.

A short time after Dr. Copeland had published his observations, Mr. Maunder challenged the assertion[2] that in the Nova "the spectrum is not so much a continuous one, interrupted by dark lines and dusky bands, as *a not very luminous spectrum upon which a series of bright bands are superposed.*" The accuracy of the observations was not, however, doubted, nor was the importance of the view denied.

The main objection urged by Mr. Maunder was that Dr. Copeland's measures of the bright parts in Nova Orionis did not exactly agree with laboratory determinations of the wave-lengths of the hydro-carbon bands. He does not, however, make mention of the fact that there are two perfectly distinct sets of bands seen under different conditions. Nor does he refer to the "laboratory work" which has been relied on to show that they are not hydro-carbon bands at all. The mean of Dr. Copeland's measures of the bright line in the green, beginning a band, is 516·2. The wave-length of the first carbon fluting of one series is given by Thalén as 516·4, which, therefore, gives a difference of 0002 in the two determinations. The line measured by Dr. Copeland at 513·7 is said by Mr. Maunder scarcely to support his view, since the second maximum of the carbon fluting has a wave-length 512·8, and of the blue carbon fluting it is noted, "The third hydro-carbon band, that in the blue with wave-length for its less refrangible edge 473·7, is indeed not far from the bright space Dr. Copeland has observed at λ 472·2, but the correspondence is certainly not very exact." Since this criticism was made, however, it has been shown that at different temperatures the maximum of the blue carbon fluting may shift from 468 to 474, so that Dr. Copeland's measures may represent the exact position of the band in the Nova.

But it is evident that a vast difference must exist between the accuracy attainable in the observatory and in the laboratory. Dr. Copeland's measures appear to give the smallest probable error in the determination of wave-lengths in such an object as Nova Orionis, yet he measured the brightest band once at 517·4 and on the following evening at 515·6, a difference of 0018. The difference of the observations *inter se* exceeds any of the differences between the bright parts measured by Dr. Copeland and the accepted wave-lengths of the carbon bands; nevertheless Mr. Maunder says the observations are "undoubtedly very accurate," hence it cannot reasonably be argued that the bright bands are not carbon because of a want of exact coincidence with those measured in the laboratory.

Mr. Maunder also notes that "the second band in order of brightness in the hydro-carbon spectrum begins at λ 563·4. This is certainly non-existent in spectra of the third type; a broad dark band—No. 4 in Dunér's nomenclature and my own, wave-length 564·2 to 559·2—occupies the very place." This contention, however, is no longer allowable, since the recent researches show that the carbon fluting of one series at 563·4 is masked by the absorption of the first manganese fluting at 557·6, and the same argument might be employed to abolish carbon from many cometary spectra.

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[1] *Copernicus*, vol. ii. p. 227.
[2] *Monthly Notices*, vol. xlvii. p. 54.
[3] *Astr. Nachr.*, No. 2704.
[4] *Astr. Nachr.*, No. 2707.
[5] *Comptes rendus*, vol. cii. p. 41, 1886.

[1] *Comptes rendus*, vol. cii. p. 356, 1886.
[2] *Monthly Notices R.A.S.*, xlvi. p. 284.

My recent work has entirely justified Dr. Copeland's observations, and to him certainly belongs the credit of having established the existence of the carbon bands bright in a new star. J. NORMAN LOCKYER.

ON THE SOARING OF BIRDS.

THE interesting problem of the soaring of birds, though repeatedly discussed, especially in NATURE, has not yet found a satisfactory solution. This is the explanation I propose.

Suppose that a bird soaring horizontally with a certain velocity enters a current of air cutting his own course rectangularly. The bird will be seized and partly borne by the wind. Instead of passing by calm the distance *a* to *b*, he will advance from *a* to *c* in the same space of time (see Fig. 1; the arrow *ef* indicating the direction of the wind, and the cross-lines the length-axis of the wing-area). The way *a* to *c* evidently being longer than *a* to *b*, the bird, on arriving at *c*, has a greater absolute velocity than if he had pursued, in a calm, his course *a* to *b*. It is equally evident that, if the initial velocity of the bird and the velocity of the wind are properly adapted, the velocity of the bird at the point *c* can, in spite of the resistance of the air to his advancing, be greater than at *a*. If arriving at *c* the bird can turn against the wind[1] without considerable loss of velocity, it is clear that he is able to continue his new course for a short space, before his velocity sinks to the initial velocity which he possessed at the point *a*. During this part of his course, the relative velocity of the bird (with relation to the air) is more than twice the absolute velocity of the wind, supposing the initial velocity of the bird equal or superior to that of the wind. Let *d* be the point where the absolute velocity of the bird has sunk to the initial velocity. If the bird turns at *d*, so that his course crosses the direction of the wind at right angles, he is again ready to begin the same course as when starting from *a*. Thus, on the way *a* to *c* the absolute velocity increases, on *c* to *d* it diminishes as much.

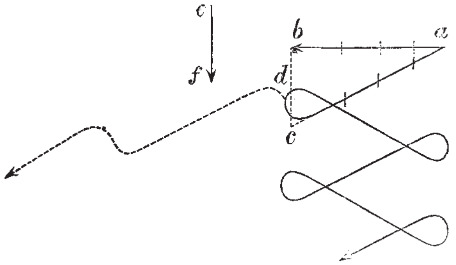

FIG. 1.

Let us now suppose the direction of the wing-plane unchanged: the course of the bird will no longer lie in the horizontal plane, but, from reasons now easily understood, *a* to *c* will gradually drop down to the earth, according as the relative velocity diminishes; on the other hand, *c* to *d* will rise according to the increment of the relative velocity. Which will be the greater, the sinking or the rising, depends on several circumstances, but principally on the force of the wind, the adaptation of the wing-plane, the size and form of the bird and the corresponding proportions between the bearing of the wings and the resistance of the air. This resistance is, of course, in proportion to the weight, less to the advancing of large birds than to the advancing of small birds. This is the reason why large and heavy birds are the best soarers.

It results from this that a bird suitably built for the purpose can not only maintain the same level without working his wings, by a uniform and moderate wind, but also gain in height by adroit movements.

It may perhaps be objected that, according to this scheme, the course of the bird will not be spiral, but run in figures of eights gradually moving in the direction of the wind or in continuous windings on the one or on the other side and partly with the wind (Fig. 1). Indeed it is likely that the movements of the birds will often prove that they profit by this principle in manœuvres the purpose of which has not yet been understood.

The spiral soaring is still to be explained. I think we must suppose that commodiousness is the principal motive thereof. Let us fancy that a bird, having acquired the necessary initial velocity, soars in a calm without working his wings, not in a rectilinear course, but by suitable inclinations and turnings of the wings in circular courses. We know that, in order to perform this manœuvre, the bird drops the interior wing a little and raises the exterior wing just as much, so that the wing-plane, during this motion, forms a conic ring, the top of the cone pointing downwards. If the velocity did not diminish, the bird would be able to continue this course indefinitely, or he would rise or sink in a screw-formed course, according as the velocity should increase or diminish. By greater inclination of the wing-plane to the axis of the cone, the circles would become narrower; by diminishing inclination, they would become wider: both these motions are easily produced by minimal changes of the form of the wing-plane or of the place of the centre of gravity. Let us further suppose that the stratum in which the bird soars is continually moving in a certain direction. From the moment the course of the bird is perpendicular to the direction of the wind (point *a* in Fig. 2) till the moment it grows parallel with it (*b*), the bird obtains from the wind an addition to his absolute velocity (not considering the loss occasioned by the resistance of the air) and also an increment of velocity from the moment his course deviates from the direction of the wind (*b*) till the moment it grows perpendicular to it (*c*). From this moment again the absolute velocity gradually diminishes, till, at last, at the point *f*, it reaches its minimum. From this point (*f*),

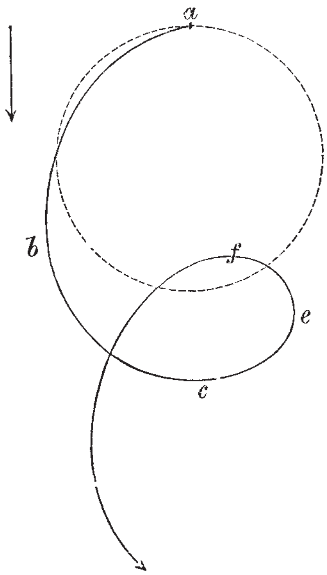

FIG. 2.

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[1] It has long been acknowledged that some birds possess the power of changing their direction without any sensible loss of velocity.